Evidence for Nutrient Limitation and Sources Causing Hypoxia on the Louisiana Shelf

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Abstract

The conclusion that there has been an increase in the severity or areal coverage of summer oxygen depletion is dependent on knowledge of other coastal systems, nutrient limitations on the modern phytoplankton, and analysis of sedimentary records. Five hypotheses may explain these changes: 1) overland flow through coastal wetlands has been severely restricted this century, 2) Increased nutrient concentration in the Mississippi River since the 1950s, 3) intrusions of offshore waters causing a natural long-term variability that is misinterpreted as a permanent change, 4) Short- or long-term climate changes (riverine fluctuations), and, 5) increased loadings from estuarine sources. Based on the available data, the strong inference is that only Hypothesis No. 2 is sufficient to explain these changes in an efficacious and non-contradictory way.

Introduction

The conclusion that there has been an increase in the severity or areal coverage of summer hypoxia (e.g., Rabalais, et al., this volume) is dependent on knowledge of other coastal systems, nutrient requirements of phytoplankton, and analysis of sedimentary records. Six hypotheses are proposed to explain these changes: 1) overland flow through coastal wetlands has declined severely this century, 2) increased nutrient and organic loadings from estuarine sources, 3) intrusions of offshore waters causing a natural long-term variability that is misinterpreted as a permanent change, 4) short- or long-term climate changes (riverine fluctuations), 5) organic loading from the Mississippi River causes the lack of oxygen, and, 6) the increased nutrient concentration in the Mississippi River since the 1950s. Each of these hypotheses has been tested, and the results outlined in the following discussion.

Six Hypotheses

Hypothesis No. 1

Overland flow through coastal wetlands has been severely restricted this century by navigation and flood control levees on the Mississippi River. The consequence of this disruption in the natural (geologic) hydrology is to reduce the removal of nutrients from water flowing over and through coastal wetlands.

These hypotheses can be tested by examining the amount of flow restricted by these levees, determining the likelihood of nutrient removal in the area available, and comparing nutrient concentrations in the Mississippi River and receiving water bodies.

The amount of flow reduction from human-made levees was determined by Kesel (1988) as part of an effort to measure the effects on suspended sediment transport. He said:

> *"The proportion of water discharge above bankfull was computed from daily records and that proportion used to determine the suspended load carried by above bankfull flows. The amount of sediment during this period that would have been available for overbank flow was estimated to be 163.4 × 10^6 metric tons. This amounted to 14 percent of the suspended sediment carried during flood flows, but only 2.6 percent of the total suspended load carried during the entire 34-yr period."* (Kesel, 1988).

A 2.6 percent reduction in suspended sediment (and therefore nutrient) flow is thus an insignificant proportion of the total flow, which has also tripled in nitrate concentration. Furthermore, there is a mismatch of overland flow potential and river stage. Water levels on the marsh peak in late summer, whereas the peak river stage is in the spring. This mismatch minimizes, rather than maximizes any potential ability of wetlands to remove nutrients limiting phytoplankton growth.

Furthermore, the ability of coastal wetlands to absorb nutrients is not equal among wetland types, and, in fact, most of Louisiana's coastal wetlands appear to export the dissolved nutrient forms that limit phytoplankton growth (Table 6). In addition, the Louisiana experience is that the conditions necessary for optimum nutrient removal are not met (Table 7). There are simply not enough forested freshwater wetlands to remove even 10 percent of the historically low nutrient concentration (prior to 1950) through overland flow.

Table 6.
Import (I) and Export (E) of nitrogen and phosphorus from wetlands through overland flow (g m^{-2} y^{-}).

Location	Wetland	DN	TN	DIP	TP
Fourleague Bay	fresh		E-NO3 E-NH4 E-TKN	E	E
Bayou Chevreuil	swamp	I-NO3 I-NH4 E-DON	I-3.87	E-OP-0.1 E-TP-	I-1.71
Barataria Bay	salt and brackish	E-NO3 E-NH4 E-DON	E-TKN	I	E
Fourleague Bay	salt and brackish	E-NO3 E-NH4 E-DON	E-TKN	E	E
Bonnet Carre'	fresh				

Table 7.
Nutrient removal optimization.

Favored by or indicated by	Louisiana Experience
Long contact time (days/week)	Short (1 day, Bonnet Carre', an engineered crevasse)
Sufficient area	Area restricted/limited by existing upland development and landowner concerns; not extensive relative to loading rates
Higher loading =less retention	Not documented in Louisiana, but is a general experience nationwide
Subsurface flow higher removal than surface flow	Nitrate and phosphate exported from all coastal wetlands *but* swamps

The conclusion is to reject Hypothesis No. 1.

Hypothesis No. 2

Nutrient and organic loadings from estuarine sources has released organic matter offshore in increasing amounts and caused hypoxic water formation offshore.

This hypothesis can be tested by examining the historical progression of estuarine eutrophication, the likelihood of estuarine-offshore exchanges, and the net fluxes.

Estuarine exchanges with offshore waters clearly exist. Evidence for this is the inverse relationship between estuarine salinity and Mississippi River discharge (Wiseman et al. 1990). Eutrophication of the estuaries has also occurred (Rabalais et al. 1995). Therefore, it is possible to exchange nutrients from inshore estuaries to offshore. However, if there were significant dominance of nutrients in either direction (offshore to inshore, or vice-versa), then the sedimentary record of diatom production in nearshore and estuarine sediments would be similar. The deposition/accumulation of biogenic silica (a surrogate for diatom production) is strikingly different in both end members. The accumulation rate of BSi in estuarine waters reflects the use of fertilizer in the estuarine basin and the accumulation in offshore waters is coincidental with the nutrient loading from the Mississippi River (Turner and Rabalais 1994; Turner et al., unpublished). Thus, there is no coherence between nutrient loadings in the estuarine and offshore waters, and Hypothesis No. 2 is not supported. Further, a crude nutrient and carbon budget for estuarine and offshore waters is dominated by the in situ loadings, not the estuarine sources.

The conclusion is to reject Hypothesis No. 2.

Hypothesis No. 3

Intrusions of offshore waters cause a natural long-term variability that is misinterpreted as a permanent change.

This hypothesis can be examined by documenting physical connections between the oxygen minimum layer (OML; Figure 62) found throughout the open Gulf of Mexico and the continental shelf and determining the respiration rate in the OML.

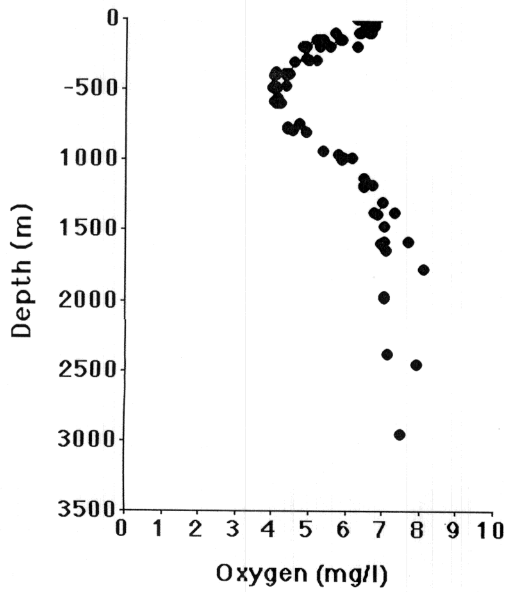

Figure 62.
The oxygen minimum layer in the open Gulf of Mexico.

Throughout years of data collection we cannot find a physical connection between the hypoxic water masses found in the OML within the GOM waters (Figure 62) and in continental shelf waters. Furthermore, the oxygen consumption rates in the OML are insufficient (by several orders of magnitude) to account for the observed seasonal decline in oxygen concentration on the shelf.

The conclusion is to reject Hypothesis No. 3.

Hypothesis No. 4
Short- or long-term climate changes (riverine fluctuations) occur and are mis-interpreted as an increase in hypoxia.

Hypothesis No. 4 is not supported by examination of the river discharge records (Figure 63) or the sea level rise records, which act as surrogates of major physical forcing functions on the continental shelf.

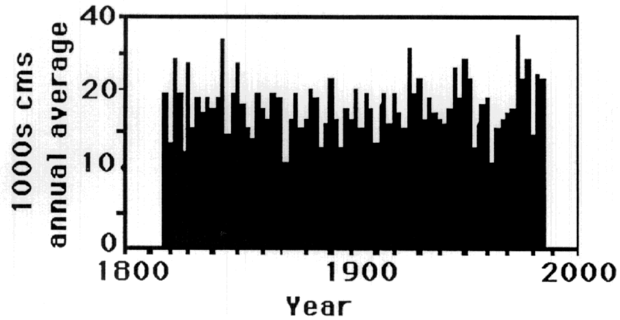

Figure 63.
The discharge of the Mississippi River at Vicksburg, Miss. from the middle of the last century to present.

The conclusion is to reject Hypothesis No. 4.

Hypothesis No. 5
Organic loading from the Mississippi River causes hypoxic water mass formation.

The amount of organic loading in the Mississippi River is not large enough to account for the observed decline in oxygen over such a large area. There is much more oxygen removed each summer than can be supported by carbon introduced by the river. Also, the chemical signature of the carbon ($^{12/13}C$ isotopic ratio) found in material from the collection devices placed in offshore waters, is different than in the carbon from the river.

The conclusion is to reject Hypothesis No. 5.

Hypothesis No. 6
Nutrient loading from the Mississippi River causes hypoxic water mass formation.

It appears that the nutrients in the Mississippi River have changed in the same scale and in the amounts necessary to cause the observed hypoxia (Figure 64; Turner and Rabalais 1991; Rabalais et al., 1996, in press). Indicators of oxygen stress are coincidental with the changes in increased organic loading, as well (Sen Gupta et al. 1996; Rabalais et al., 1996).

The conclusion is not to reject Hypothesis No. 6.

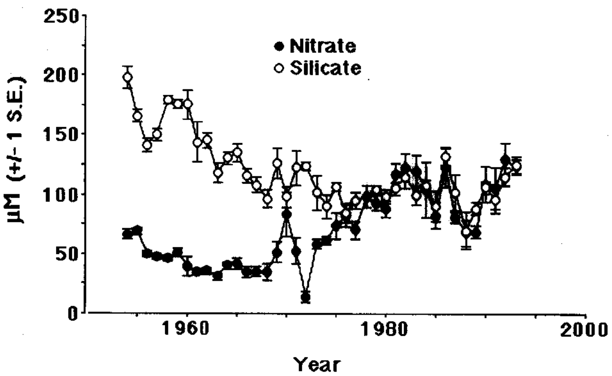

Figure 64.
Nitrate and silicate concentrations in the Mississippi River (from Rabalais et al., in press).

Summary

Based on the available data, there is a strong inference that only Hypothesis No. 6 is sufficient to explain these changes in a efficacious and non-contradictory way. Management measures based on Hypotheses No. 1–5 are likely to be wasted efforts.

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Presentation Discussion

Eugene Turner (Louisiana State University—Baton Rouge, LA)

Bob Wayland *(U.S. Environmental Protection Agency—Washington D.C.)* commented that Eugene Turner seemed to have taken a bottom-of-the-funnel approach to assessing wetland destruction or hydro modification of the river. He asked whether other changes which took place further up the river system might have also contributed to the problem and, therefore, reversal of those upriver problems might also be considered as part of the solution.

Eugene Turner agreed that the nitrate loading is a cause-and-effect relationship upriver as well. However, he pointed out that regardless of the cause (land-use changes are strongly implicated), the major issue is the loading at the river mouth.

Robert Wayland replied that he understood Eugene Turner was discussing overland flow and loss of the attenuation capacity of the wetlands in the lower river, but he was suggesting that the loss of riparian wetlands upstream might have also been a contributing factor.

Eddie Funderburg *(LSU Agricultural Center—Baton Rouge, LA)* opened his comment by saying that there have been multiple sources of nutrients identified as contributors to the river, yet the focus is primarily on fertilizers, particularly nitrogen fertilizers. He asked if there have been correlations developed for other sources, for example, wastewater treatment plants which have been brought on-line since 1950, automobile emissions, or gasoline consumption. It is possible that the graphic relationship would look similar to the relationship shown for nitrogen and phosphorous use.

Eugene Turner replied to his comment by saying that for each of the other sources there is not the same type of relationship or quantity from atmospheric sources as there is from fertilizer use. Atmospheric sources can, in fact, come off the farmland as ammonia and deposit as nitrate. The numbers from sewage plants demonstrate that the contributions are not as significant as the source material in terms of quantity.

Eddie Funderburg then asked Eugene Turner how 20 percent was derived as the amount of nutrient contribution from farmlands to the Mississippi River.

Eugene Turner replied that they assessed the change in nutrient loading and measured how much fertilizer was applied in each of those county/states in the drainage basin. To explain the changes of nitrate in the river, it is necessary to assess if enough fertilizer was applied in the drainage basin to account for the nitrate change in the river.

Finally, he said that there is enough fertilizer applied in the Mississippi River Basin to affect that change and that means that there needs to be only a 20 percent leakage from the system. No system has 100 percent retention efficiency. This is what is typically found in other rivers as well for agriculture systems.

Eddie Funderburg agreed there is some leakage, but questioned that Eugene Turner could demonstrate, using field studies, that 20 percent was moving from land into the Mississippi River.

Eugene Turner countered by saying that people have traced nitrogen isotopes and determined whole nitrogen budgets. In fact, one study was conducted in Iowa in the 1960's.

This conference may or may not decide that to reduce the load it is necessary to more quantitatively determine the exact sources so that risk analyses and cost benefit analyses can be conducted.

Len Bahr made a general comment saying the last two papers presented touched upon an important issue. Unfortunately, the format of the conference was not set up to really discuss the theoretical questions. He said the coastal restoration program is not driven by the hypoxic zone. The need to restore and mitigate wetland losses of 35 square miles per year is reason enough for the program to exist. The theoretical bonus of being able to reduce some of the eutrophication of the nearshore waters is real and should be explored. It should be a major part of the next conference on the hypoxia area.

Lon Strong *(USDA / NRCS—Jackson, MS)* reiterated a comment made by Eugene Turner that Mitch and his co-author stated that subsurface flow systems were a lot more efficient than surface flow systems. He asked Eugene Turner if he was referring to man-made or natural systems.

Eugene Turner said that because the contact time is increased, it is a general observation that natural systems, where effluent flows below ground, were more efficient than above ground systems.

Ann Burruss *(Coalition to Restore Coastal Louisiana—Baton Rouge, LA)* asked how the nitrogen concentration in the upper part of the Barataria Bay would compare to the concentration in the Mississippi River.

Eugene Turner replied that the nitrogen concentration in the upper part of Barataria Bay is much lower than in the Mississippi River. The concentrations were calculated by doing a transect for the past year and will continue for another year or two. There are 37 stations off-shore as far as Bayou Seville.